Simultaneous Aerodynamic Analysis and Design Optimization (SAADO) for a 3D Flexible Wing

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Motivation

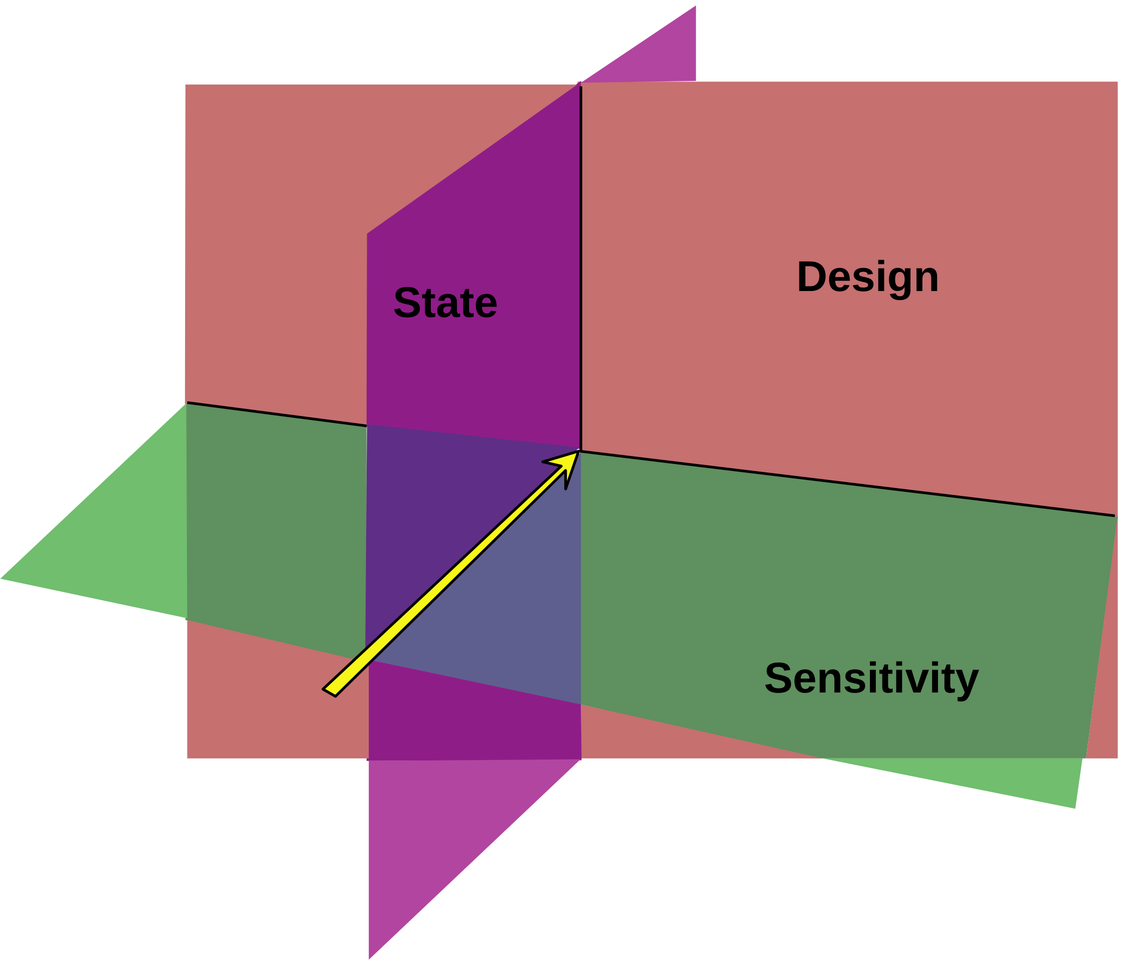
- Multidisciplinary Design Optimization with high fidelity (nonlinear) PDE analyses
  - Loosely coupled discipline interactions
  - Use validated legacy codes
  - Minimize implementation issues

- Reduce computation cost from conventional optimization

Outline

- Conventional Approach
- Optimization Challenges
- SAADO Approach
- Process Implementation
- Application Problems
- Results
- Conclusions

Conventional Approach



$$\min_{\beta} F(Q,u,X,\beta)$$

subject to constraints

$$g_i(Q,u,X,\beta) \leq 0, i=1,2,\ldots m$$

β **design variables**

X **computational mesh**

$$\left.\begin{array}{l} Q\,(u,X,\beta) \\ u\,(Q,X,\beta) \end{array}\right\} \text{solutions of coupled aero-struct equations}$$

$$\left.\begin{array}{l} Q' \\ u' \end{array}\right\} \text{solutions of coupled aero-struct sensitivity equations}$$

Optimization Challenges

- **Why SAADO?**
  - **Minimize modifications to discipline analysis codes**
  - **Reduce the cost incurred by well-converged, iterative function and sensitivity analyses at non-optimal points in design space**

- **How SAADO?**
  - **Interleaf optimization updates with iterative discipline and system analyses**
  - **Require better convergence for function and sensitivity analyses as optimization progresses**

- **Past SAADO**
  - **Demonstrated for 1D, 2D, and 3D aerodynamic applications (single discipline)**

- **Flexible 3D SAADO goals**
  - **Results which agree with conventional optimization**
  - **Computational cost less than conventional optimization**

SAADO Approach

Partial convergence implies:

- **Approximate functions (state) and gradients (sensitivities)**
- **Infeasibility in early design steps**

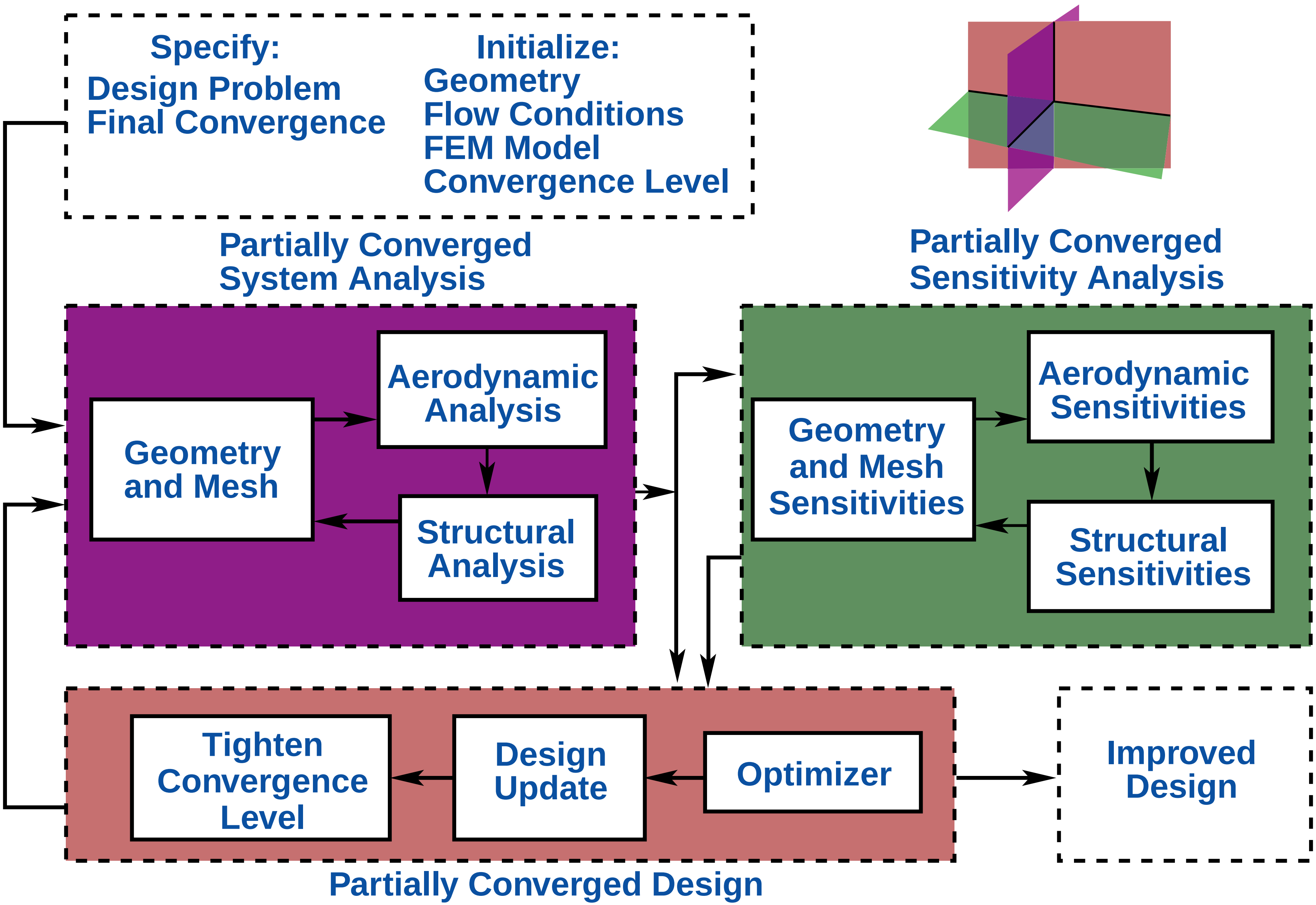
$$R(Q, X) \neq 0$$
$$Ku - L \neq 0$$

- **Contribution to reduction of design variable domain**

$$R + \frac{\partial R}{\partial Q}\Delta Q + \frac{\partial R}{\partial X}(\Delta u) + \frac{\partial R}{\partial X} X' \Delta\beta = 0$$

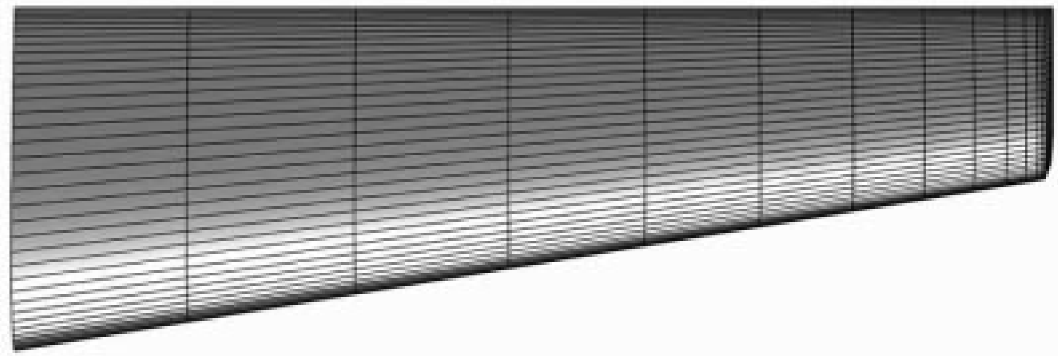
$$Ku - L - \frac{\partial L}{\partial Q}\Delta Q + \left(K - \frac{\partial L}{\partial X}\right)\Delta u + \left[\frac{\partial K}{\partial X}u - \frac{\partial L}{\partial X}\right] X' \Delta\beta = 0$$

Process Implementation

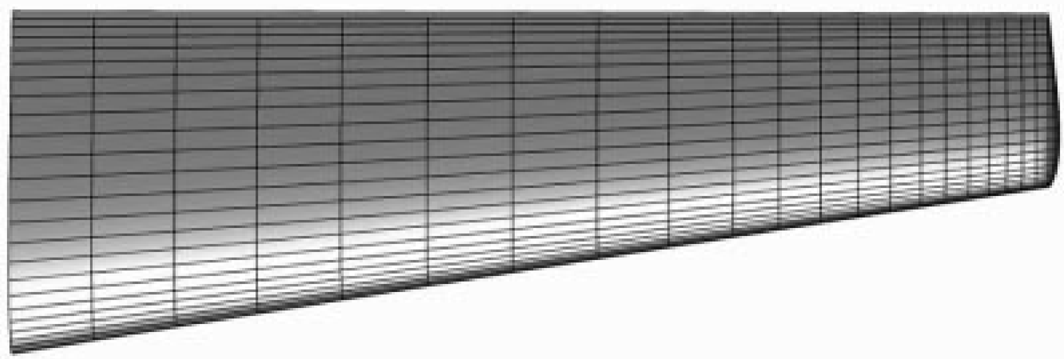


Process Implementation
Computational Meshes

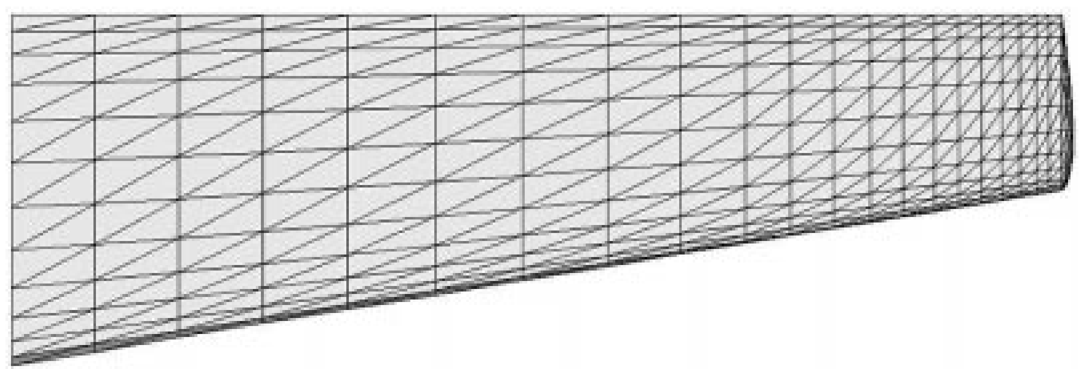
97x17x25
CFD mesh
(rigid wing
AIAA 99-3296)



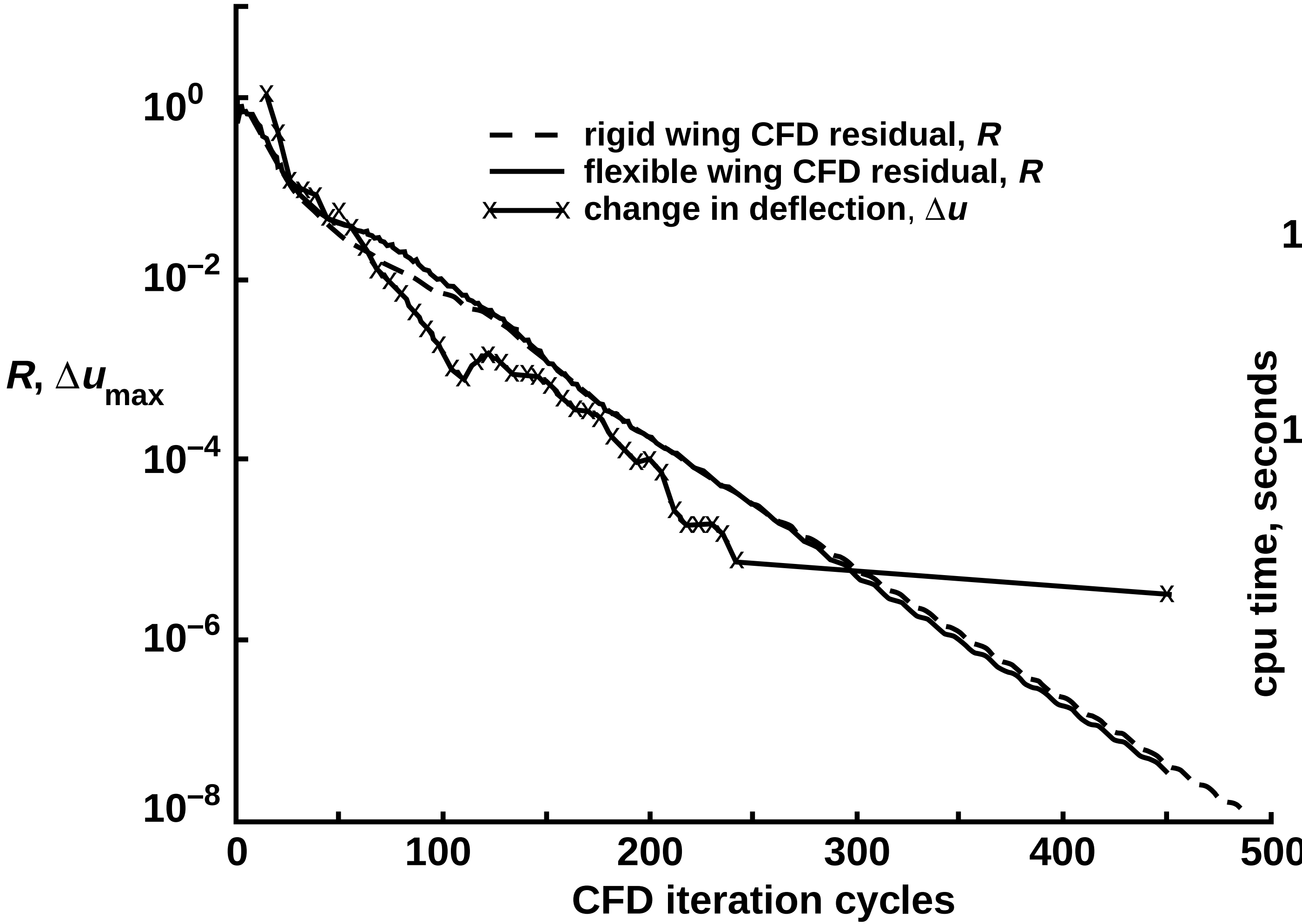
73x25x25
CFD mesh
(flexible wing)

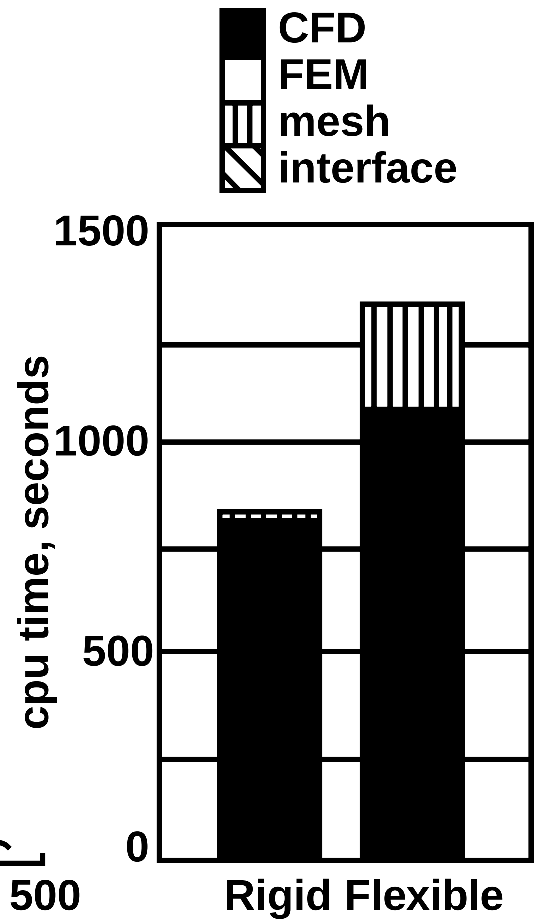


1110 truss elements
2141 CST elements
FEM mesh

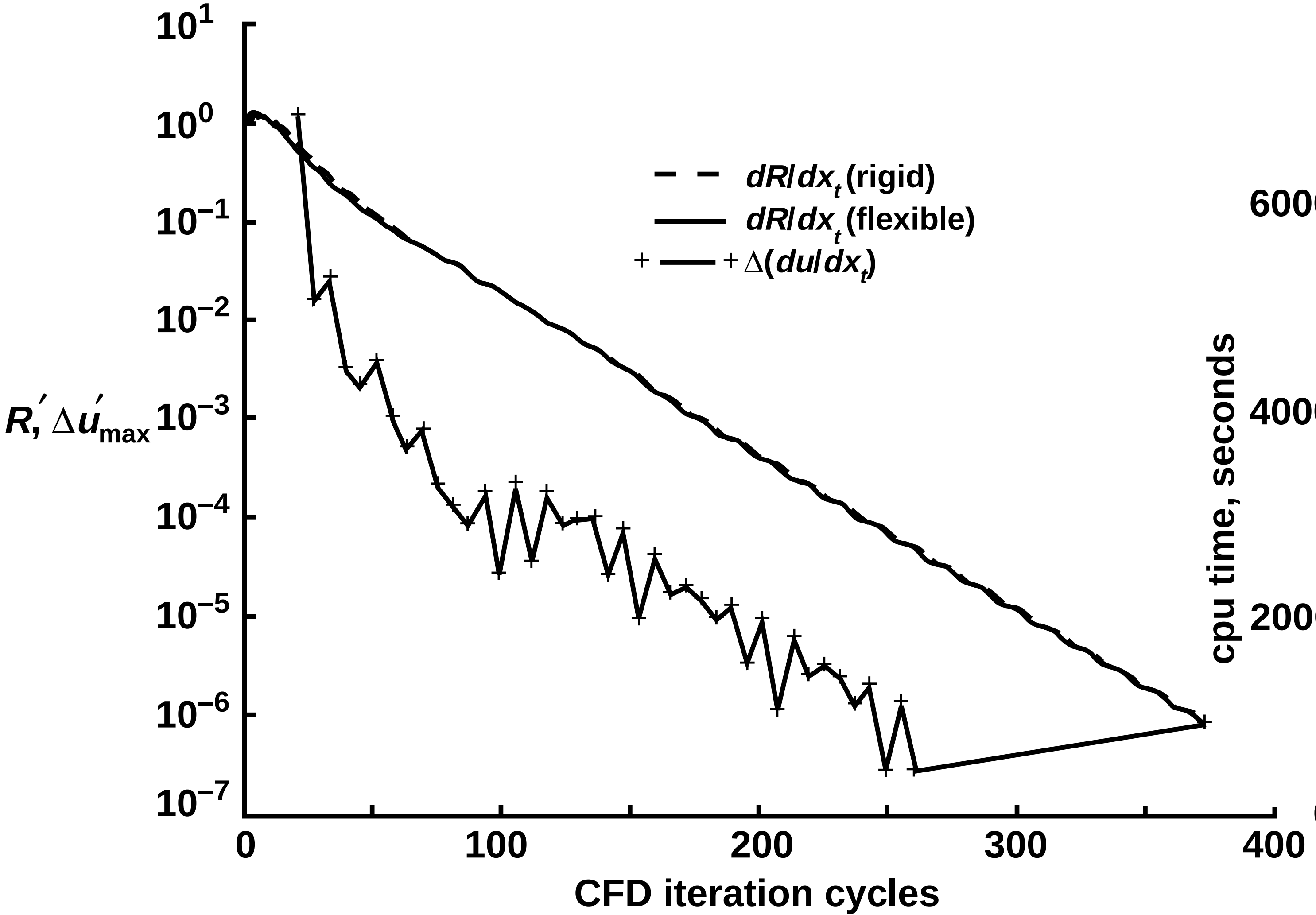


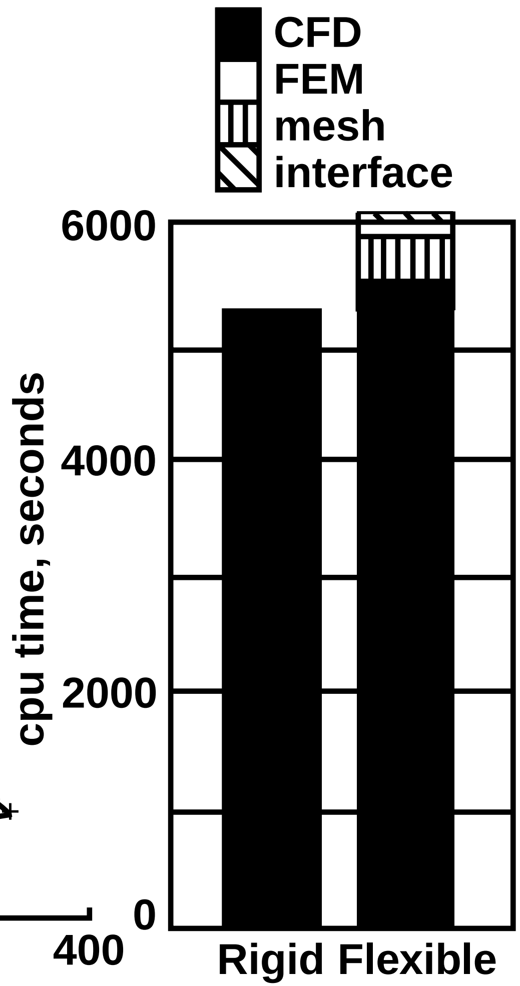
Process Implementation
Aerodynamics / Structures Coupling





Process Implementation
Aerodynamics / Structures Derivative Coupling





Application Problems
Aerodynamic Shape Optimization of a 3D Flexible Wing

- **Objective function: negative lift to drag ratio, –L/D**
- **Constraints:**

	"flexible"	"rigid"
• minimum payload:	$C_L * S * q_\infty - W \geq L_{min}$	$C_L * S \geq L_{min}$
• maximum compliance:	$\oiint p\, u \cdot ds \leq P_{min}$	———
• maximum bending moment:	———	$C_\ell \leq C_{\ell_{max}}$
• maximum pitching moment:	$C_m \leq C_{m_{max}}$	$C_m \leq C_{m_{max}}$
• minimum leading edge radius:	yes	yes

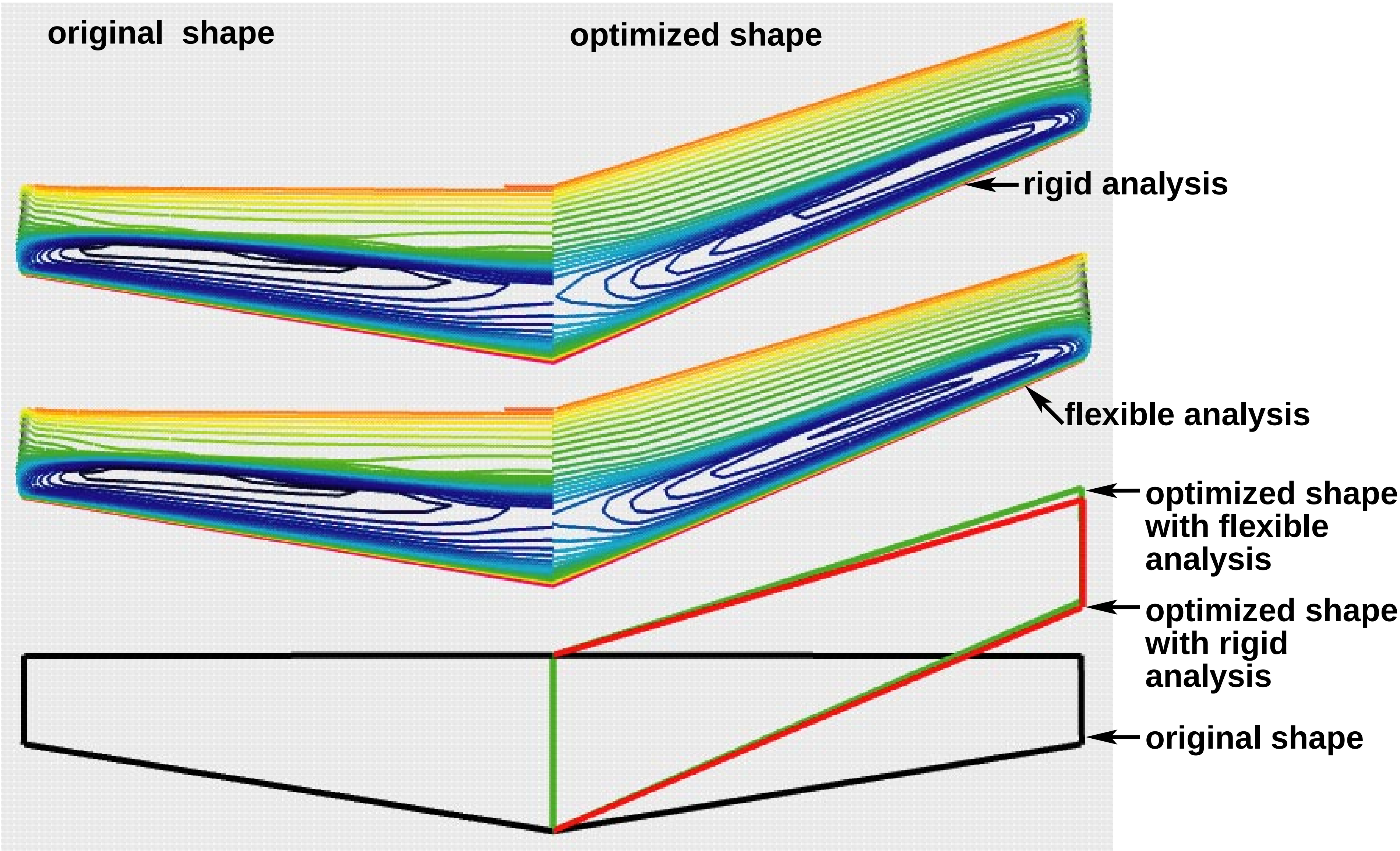
- **Design variables: planform and section**

Application Problems

$M_\infty = 0.8$, $\alpha = 1°$

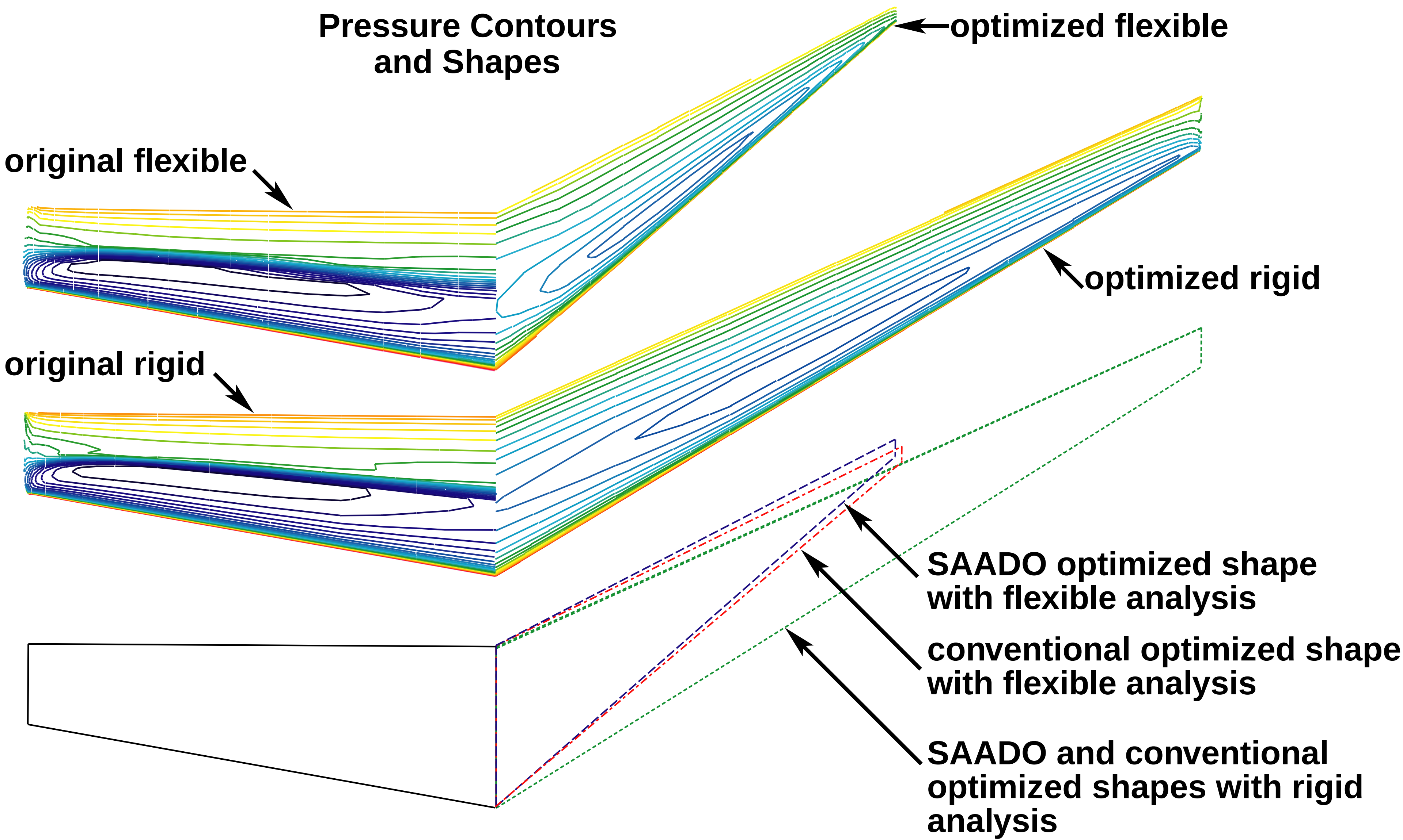
- Two planform design variable
  - Ensure comparable results with conventional approach
  - Rigid (from AIAA-99-3296)
- Eight-design-variable problems
  - Section variables and planform variables
  - Rigid (shown at AIAA 14th CFD Conference)

Two Design Variable Problems
Design Results

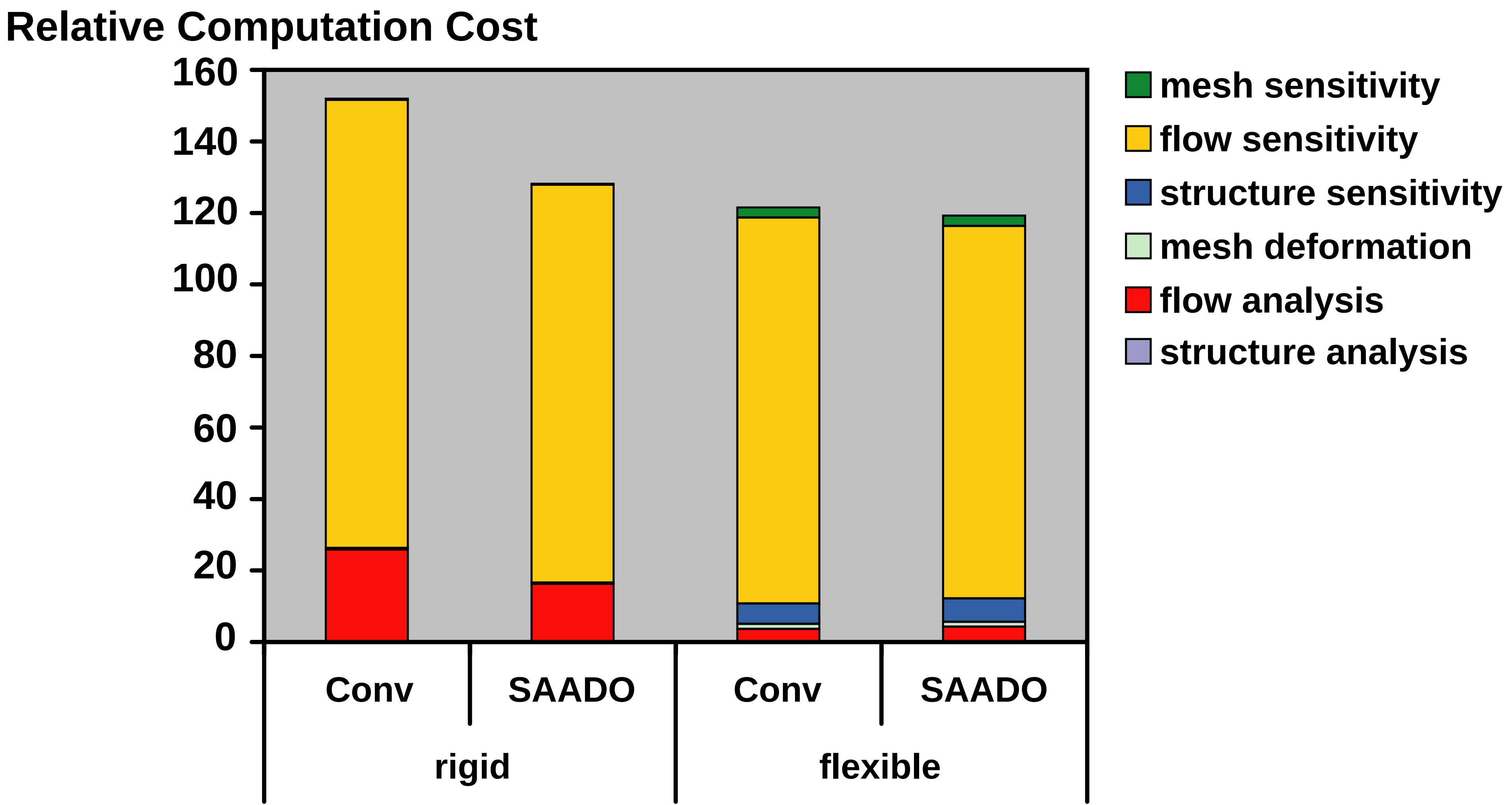


Eight-Design-Variable Problems

$M_\infty = 0.8$, $\alpha = 1°$



8-DV Optimization Problems
Computation Cost



Conclusions

- Initial flexible 3D wing SAADO results obtained, demonstrating feasibility for dual simultaneity
- SAADO finds the same or similar local minimum as conventional optimization technique
- SAADO requires few modifications to the function and sensitivity analysis codes
- SAADO can be computationally more efficient than conventional techniques, but may be problem dependent
- Gradient computation times dominate SAADO

Open Questions

- Gradient cost
  - adjoint approach for loosely coupled analyses?
  - code (compiler) optimization for AD code?
  - other approximations or methods?
- Optimizer control
- Sensitivity analyses error control

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